



Integrating Heritage Conservation and Smart City Planning: A Socio-Technical Framework for Sustainable Adaptive Reuse

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ABSTRACT

As the pressure of urban development grows, the loss of resources for heritage buildings and the demands of modern life are creating new threats. Although adaptive reuse has become an important sustainable strategy, its comprehensive integration with smart city technologies in the context of conservation is still relatively unexplored. This research will endeavor to develop a socio-technical framework which unifies smart technology with heritage conservation for resilient urban spaces. With the help of a systematic literature review (SLR) approach, the study examines the convergence of technical building effectiveness and human-centred social response. The theoretical framework provides a theoretical synergy between Socio-Technical Systems (STS) and Regenerative Design through a paradigm that goes beyond the typical sustainability levels. The study demonstrates that the deployment of artificial intelligence based sensor systems, powered automated lighting optimization, and remote occupancy management that extends the lifecycle of the building substantially promote user place attachment. As for the authors, their findings suggest a joint scheme, wherein their analysis suggests that transforming heritage resources into smart-functional spaces, e.g. intelligent retail or coffee places, reduces embodied carbon and upholds urban cultural identity. The findings highlight that the interplay between technical engineering thresholds and restorative human experiences is paramount to achieving resilient social infrastructures that address SDG 11, Sustainable City and Community.

INTRODUCTION

Adaptive reuse is recognized as a multifaceted preservation strategy that extends beyond the simple act of repurposing existing structures for commercial or mixed-use applications. Originating as a primary means of structural preservation in the late 20th century (Austin, 1988), this concept now requires a more systemic approach to address the complexities of contemporary urban environments. Today, heritage buildings are increasingly viewed not merely as static physical entities embodying aesthetic and historical significance (Attoe, 1984), but rather as dynamic urban resources that possess substantial cultural and environmental importance. In light of accelerating urbanization, preserving these buildings serves not only to safeguard local identity but also responds to challenges such as land scarcity and the necessity for sustainable development. The adaptive reuse model presents an effective environmental strategy for extending the life cycle of structures by allowing for the retention of existing systems and materials while mitigating the environmental impact associated with new construction. This approach helps reduce "embodied carbon" and curtails urban sprawl by avoiding the carbon-heavy processes linked to demolition and reconstruction.

However, in practice, adaptive reuse often encounters what is referred to as a 'functional gap.' This phenomenon arises when existing structures struggle to meet modern performance expectations related to energy efficiency, digital connectivity, and occupant comfort. To bridge this gap, a shift towards a socio-technical framework is essential. This study posits that integrating smart city technologies – such as artificial intelligence (AI), Internet of Things (IoT) sensors, and automated environmental controls – could transform heritage buildings into resilient social infrastructures. By aligning technical building performance with user-centric restorative needs, adaptive reuse can evolve from being merely an act of conservation into a proactive regenerative urban strategy. Drawing on research conducted by Yung and Chan, this paper asserts that cultivating sustainable elements within cities may depend on an approach that harmonizes heritage preservation with contemporary technological advancements in pursuit of Sustainable Development Goal 11.

LITERATURE REVIEW

Adaptive reuse refers to the practice of repurposing objects and spaces in various ways, with multiple interpretations present across different sources. Harastoeti DH (2011) characterizes adaptive reuse as the act of employing a building or piece of furniture for a function distinct from its original purpose upon construction. Abieta & Architecture (2011) expand on this idea by citing Heritage Council Victoria's (2011) perspective that "a space can be infused with life" rather than being deemed obsolete. This concept of layering back is rooted in the belief that historically significant structures should be preserved while ensuring the maintenance of existing buildings. Ultimately, adaptive reuse seeks to maintain both historical and architectural significance while enabling flexibility for new applications. Yung & Chan (2012), in their work titled "Implementation Challenges To The Adaptive Reuse of Heritage Buildings: Towards The Goals Of Sustainable, Low Carbon Cities," argue that utilizing

adaptive strategies for repurposing existing structures can revitalize urban environments by extending the lifespan of buildings, reducing waste and demolition, promoting recycling efforts, and delivering social, economic, and cultural benefits within architectural and urban planning contexts.

Furthermore, The Burra Charter – Australia ICOMOS Charter for Places of Cultural Significance (2013) that defines adaptation as the modification of a location or its environment to serve current or future needs in a way that is both contemporary and forward-thinking. Utilization includes activities and traditional practices occurring at or around that site. Additionally, conservation principles stipulate that adaptations must have minimal impact on the site's cultural significance; major alterations to primary structures should only occur if absolutely necessary. The adaptation process may entail adding new sites or features, changing uses, or adjusting protective measures for a location. Any functional modifications must align with provision 7.2, which states that a specific use is vital for maintaining the site's ongoing relevance. According to UU No. 11 of 2010 concerning Cultural Conservation, Chapter I Article 1 No. 32, adaptive initiatives aim to apply Cultural Conservation strategies suited to modern needs through adjustments that honor and safeguard essential recognized elements.

The difference between the conventional or linear model and the circular model represented by the images below. Linear model shows the process of resources trace from the extraction to disposal site with impact of generating massive carbon debt.

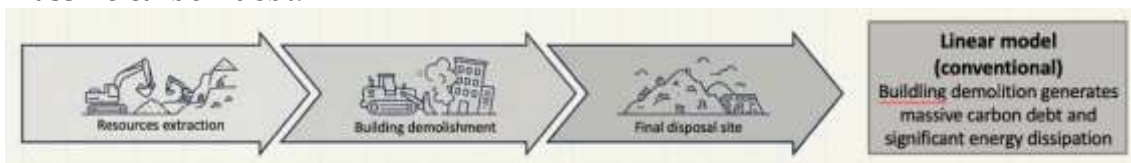


Figure 1. Regenerative circular model
(source: researcher's analysis, 2026)

While the regenerative model shows circular cycle from adaptive reuse approach that supporting the materials to be treated as resources that can be reused and stops the high emission demolition process of unused building and new building or development.

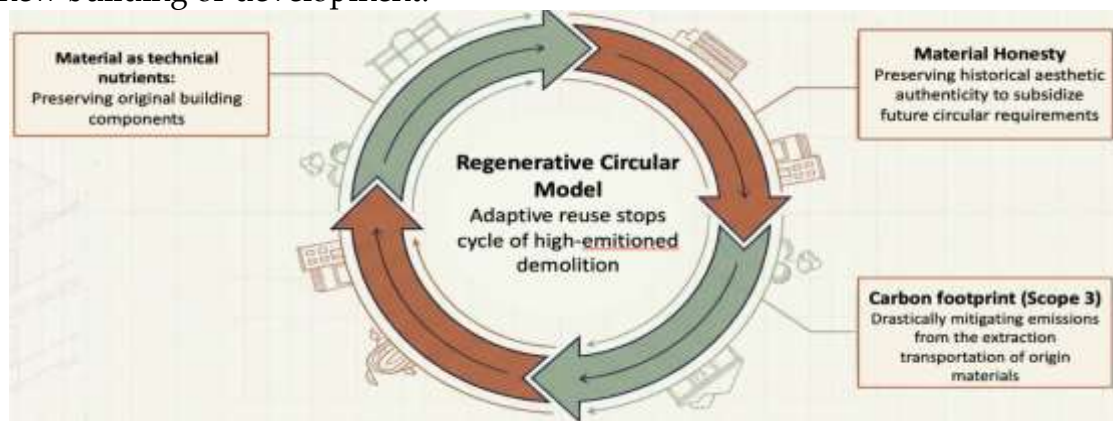


Figure 2. Regenerative circular model
(source: researcher's analysis, 2026)

Advantages and Challenges of Adaptive Reuse

Advantages of Adaptive Reuse

Understanding adaptive reuse as a strategy for achieving sustainability in the development process offers various benefits that positively impact several areas, including but not limited to:

- a. **Environmental Sustainability:** By reusing existing structures instead of constructing new ones, adaptive reuse helps diminish the environmental effects associated with new construction. This practice leads to lower consumption of natural resources, reduced energy usage, and decreased waste generation.
- b. **Heritage Preservation:** Adaptive reuse plays a vital role in maintaining historic buildings and cultural heritage, which is essential for preserving the unique character and identity of urban environments.
- c. **Economic Benefits:** The approach can stimulate economic growth by fostering new businesses and job opportunities within urban settings. Additionally, it can revitalize underused or abandoned areas, leading to increased property values and attracting new residents and enterprises.
- d. **Social Sustainability:** Adaptive reuse promotes social sustainability by creating venues for community engagement and interaction. It can also provide affordable housing options while enhancing the diversity of urban neighborhoods.
- e. **Reduced Carbon Footprint:** Utilizing existing structures lessens the carbon footprint linked to manufacturing and transporting new building materials.

Advantages of adaptive reuse

Adaptive reuse supports a more sustainable and livable urban environment through resource efficiency, preservation of historical and cultural assets, economic development support, and encouragement of social interaction within communities. However, despite these advantages in sustainable development through adaptive reuse, there are notable challenges:

- a. **Structural Limitations:** Many older buildings may be unsuitable for repurposing due to age or structural issues. Significant renovations might be necessary to meet safety codes for new uses, often resulting in high costs and lengthy timelines.
- b. **Zoning and Regulatory Hurdles:** Existing zoning laws and regulatory standards can complicate efforts to repurpose buildings. In some instances, updates to building codes may be required to facilitate adaptive reuse initiatives.
- c. **Financial Viability:** Projects focused on adaptive reuse may struggle with financial feasibility – especially in regions where property values are low or extensive renovations are needed. Securing funding may prove difficult; developers might need to explore innovative financing strategies or public-private partnerships.
- d. **Public Perception:** Resistance from community members can arise regarding adaptive reuse projects that alter historic structures or

neighborhoods. Public education and outreach could be crucial for garnering support for such endeavors.

- e. **Technical Expertise:** Successful execution of adaptive reuse projects demands specialized knowledge across disciplines like historic preservation, architecture, engineering, and construction. Finding qualified professionals with this expertise can be challenging in certain locations.

While adaptive reuse presents numerous advantages for fostering sustainable urban development, it is essential to thoughtfully address these obstacles prior to initiating such projects. With appropriate planning and implementation, however, adaptive reuse can serve as an effective mechanism for advancing sustainability in urban areas.

The Role of Adaptive Reuse in Sustainable and Regenerative Development

Adaptive reuse extends beyond merely renovating existing structures; it serves as a vital mechanism for harmonizing architectural preservation with the rapid transformations occurring in urban environments. This methodology addresses the complex challenges posed by modern urbanism through four primary dimensions:

- **Minimizing Environmental Impact and Embodied Carbon:** By retrofitting existing frameworks, adaptive reuse significantly decreases the need for new raw materials and the energy required for extensive construction. Preserving a portion of this embodied carbon is essential to the circular economy, as it directly contributes to reducing greenhouse gas emissions stemming from the repetitive cycle of demolition and reconstruction.
- **Conservation of Regenerative Heritage:** Beyond safeguarding physical structures, adaptive reuse ensures that historical narratives remain functional within the contemporary urban landscape. This approach aligns with regenerative design principles that transform dormant historic sites into active assets, thereby supporting both cultural integrity and ecological vitality within the city.
- **Enhancing Socio-Technical Community Resilience:** The establishment of a city facilitates various forms of social infrastructure that encompass all community members. User-centered adaptive reuse fosters a genuine sense of place and social cohesion, where repurposed spaces contribute positively to both mental well-being and social dynamics among users.
- **Promoting Smart Economic Development:** Effective reuse initiatives revitalize underutilized neighborhoods, fostering local economies through job creation and increased property values. Within the framework of smart city integration, these projects introduce new hubs for technological advancement, such as smart retail outlets and adaptive co-working spaces, that embrace innovation while serving as catalysts for economic growth, all while respecting the historical context of their surroundings.

The challenge lies in shifting from conventional sustainability perspectives to a regenerative socio-technical approach in heritage management within today's

context. By merging technical building capabilities with social identity, adaptive reuse stands out as a key strategy for attaining SDG 11 (Sustainable Cities and Communities). This integration is enhanced by smart technologies like IoT sensors for environmental monitoring and AI-driven energy management systems, ensuring that heritage buildings are preserved yet upgraded to meet 21st-century digital demands in urban settings.

METHODOLOGY

This research utilizes a Systematic Literature Review (SLR) combined with a qualitative-descriptive synthesis to develop an innovative socio-technical framework.

Research Design

The study adopts a systematic qualitative approach to analyze contemporary global literature focused on adaptive reuse and smart city initiatives. The main aim is to explore the convergence of technical engineering parameters (building performance) with the socio-psychological reactions of users (well-being and sense of place).

Data Collection and Selection Criteria

Data were gathered from prominent bibliographic databases, such as Scopus, Web of Science, and Google Scholar. The search criteria included terms like "Adaptive Reuse," "Smart Heritage," "Socio-Technical Framework," and "Regenerative Urbanism."

Technical and Social Variable Analysis

The analysis categorizes data into two main streams: 1) Technical Variables: Metrics for energy performance, structural integrity, integration of AI sensors, and optimization of natural ventilation/daylighting; and 2) Social Variables: Aspects such as place attachment, thermal and visual comfort, aesthetic experience, and digital accessibility for contemporary urban users.

Framework Synthesis and Validation

In the final phase, a cross-thematic synthesis is conducted to develop the Socio-Technical Framework. This framework illustrates how smart interventions can be aligned with conservation requirements to create resilient social infrastructure. The circles of the scheme represent the big aspects of regenerative approach that consist of adaptive reuse, sustainable design and smart city planning. The framework's validity is evaluated based on its correspondence with the objectives outlined in Sustainable Development Goal (SDG) 11.

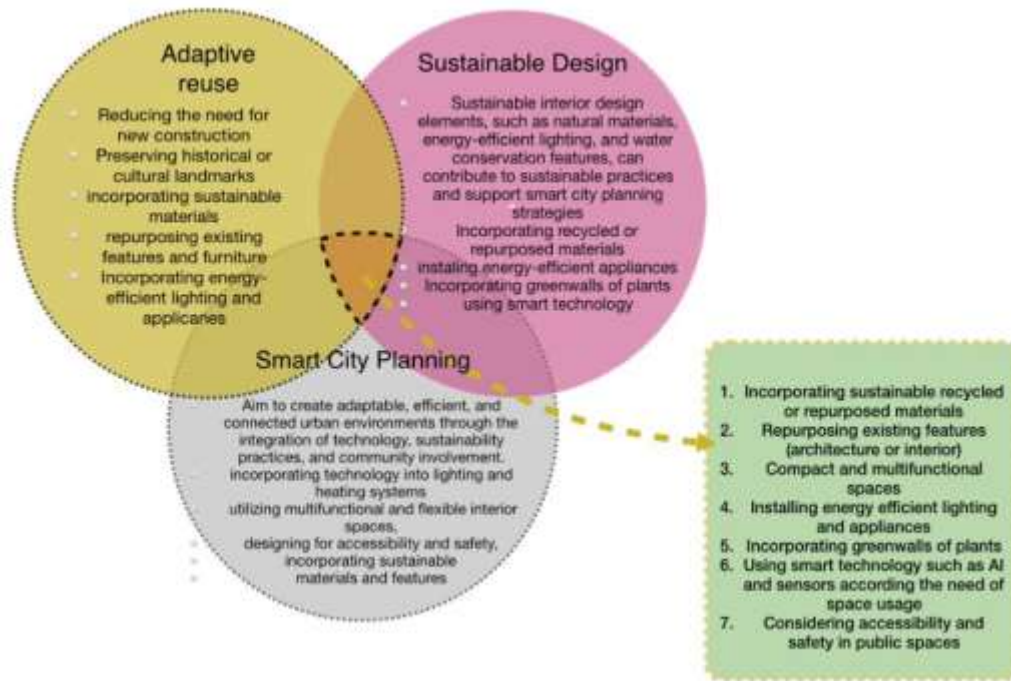


Figure 3. Elements of sustainable design in spatial design
(source: researcher's analysis, 2025)

RESEARCH RESULT AND DISCUSSION

The Multifaceted Roles of Adaptive Reuse in Socio-Technical Resilience

Moreover, adaptive reuse serves as a transformative catalyst for urban development, bridging the gap between architectural preservation and intelligent urban progress. Rather than merely repurposing existing structures, this approach fulfills several critical roles that strengthen the integration of a city's historical essence with its capacity to evolve alongside future technologies:

- Maintaining Cultural Identity and Connection to Place** – Adaptive reuse has emerged as a significant force for preserving cultural landmarks and spaces. It safeguards the *genius loci*, or spirit of place, within urban neighborhoods, fostering a deep connection to locality among residents while situating modern urban growth within the context of local history.
- Promoting Resource Circularity and Reducing Carbon Footprint**: The transformation of existing building materials minimizes the demand for new resources and reduces embodied carbon waste, aligning with eco-friendly principles. This aspect is crucial for achieving carbon reduction targets and highlights the importance of metabolic recycling of structural components over wasteful demolition cycles.
- Stimulating Regenerative Urban Renewal**: This strategy not only facilitates renovations but also revitalizes neglected or underutilized properties by creating new third places. Such areas serve as socio-economic hubs that drive neighborhood-wide rejuvenation, enhance property values, and restore economic vitality to urban corridors.
- Encouraging Community Engagement**: The participatory nature of adaptive reuse initiatives fosters collaborative design processes. This ensures that newly integrated functions, ranging from innovative retail

spaces to community gathering spots, are aligned with the genuine desires and requirements of local residents, thereby enhancing communal ownership and investment in their city.

- e. **Enhancing Spatial Versatility and Socio-Technical Adaptability:** A central objective of contemporary reuse is the creation of responsive spaces capable of adapting to fluctuating economic and environmental conditions. Heritage structures can thus accommodate diverse activities over time without significant structural or financial modifications, partly due to smart infrastructure features, such as modular designs and IoT-enabled climate management systems, being incorporated into these spaces.

Adaptive reuse exemplifies its potential to address complex urban development objectives globally in various ways. By marrying inherent historical characteristics with current socio-technical demands, planners can shift from conventional conservation methods toward creating adaptive, high-performance environments. Through this comprehensive lens, the “rebirth” of heritage buildings plays a vital role in fostering an adaptable, enduring urban social infrastructure that embraces technological advancements.

Scalar Impacts of Adaptive Reuse in Urban Development

Adaptive reuse functions as a multi-scalar catalyst within urban development, facilitating transitions toward sustainable and resilient cities through interventions ranging from the micro-interior to the macro-urban level. Within a socio-technical framework, these actions are categorized into three strategic scales:

- a. **Micro-Scale (Community Awareness and Social Identity):** At this level, adaptive reuse serves as an educational tool to foster community awareness regarding the intrinsic value of historical preservation. It transforms heritage sites into tangible narratives, strengthening the social bond between citizens and their urban history.
- b. **Meso-Scale (Building Systems and Technical Integrity):** This scale focuses on the physical and non-physical attributes of the structure, including architectural aesthetics, interior decorative elements, and building systems. The integration of smart technologies, such as IoT-based monitoring and energy-efficient retrofitting, occurs at this level, ensuring the building meets modern functional thresholds without compromising its historical integrity.
- c. **Macro-Scale (Urban Resilience and Environmental Infrastructure):** On a broader scope, adaptive reuse contributes to the resilience of neighborhoods and city-wide ecosystems. It addresses urban sprawl and land scarcity by repurposing underutilized zones into vital nodes of the city's social and technical infrastructure.

The multi-scalar approach to adaptive reuse highlights several important strategic elements that connect historic preservation with a forward-looking urban development strategy. A primary focus is on the preservation of social and cultural capital, where adaptive reuse acts as a safeguard against the loss of a

city's "collective memory". By prioritizing the preservation of historical structures over demolition, old buildings can be recycled and maintained more efficiently. This practice not only sustains the urban character and identity creating spaces that possess their own uniqueness, but also fosters continuity and psychological stability in urban environments increasingly influenced by digital change and disruption. From a sustainability perspective, adaptive reuse emerges as a significant driver for decarbonization through resource circularity. By repurposing existing buildings, there is a substantial reduction in the need for new materials and the energy-intensive processes associated with new construction. Retaining embodied carbon is vital for realizing carbon-neutral urban areas while applying circular economy principles within the construction sector. Concurrently, these initiatives contribute to socio-economic revitalization by converting underused areas into vibrant city centers. Renovated heritage structures can act as economic hubs that attract creative industries and modern businesses, thereby enhancing property values and generating jobs at the municipal level within the framework of a smart economy.

Furthermore, this framework emphasizes community resilience centered around human needs by providing high-quality third places that promote social interaction and inclusivity. These restorative settings enhance residents' mental well-being by integrating historical aesthetics with contemporary technological access. The natural limitations imposed by heritage architecture inspire socio-technical innovations; such projects demand inventive engineering solutions and function as "living laboratories" for smart heritage applications. Adaptive reuse presents a scalable model for urban planning that facilitates the integration of legacy structures into cutting-edge urban designs, thus establishing a comprehensive blueprint aimed at achieving SDG 11 goals to ensure future cities are both technologically sophisticated and historically anchored.

Adaptive Reuse as a Catalyst for Circularity and Regenerative Sustainability

Adaptive reuse has emerged as a significant aspect of the sustainable development paradigm, increasingly viewed through the perspectives of resource circularity and socio-technical resilience. As noted by Davis (2006), adaptive reuse enables sustainable practices by diminishing the need for new construction, thus preserving both the embodied energy and cultural narratives associated with heritage landmarks. This approach fosters a resilient spatial inventory, creating urban environments capable of adapting to evolving demands without incurring the ecological costs linked to demolition. The theoretical framework advocates for a departure from a linear model characterized by "take-make-waste" towards a more closed-loop system that reflects natural ecosystems. In this model, building components are treated as technical nutrients rather than future waste. Recently, adaptive reuse has become a strategic method for incorporating Circular Economy (CE) principles into urban engineering projects. By prioritizing the conservation of existing architectural structures, this strategy enhances lifecycle durability concerning structural capital, thereby allowing for increased utilization of existing material resources.

This preservation effort mitigates the metabolic burden on the environment, positioning urban fabric as a valuable long-term utility instead of simply a consumable entity. Furthermore, it plays an essential role in decarbonizing our planet by retaining embodied carbon within historical structures and avoiding the high-energy demands associated with producing steel and concrete for new building, thus providing an effective pathway toward meeting global climate objectives. Incorporating systemic resource salvage and upcycling techniques not only adds aesthetic and functional value to heritage materials but also enhances the circularity of this model with greater functionality. This integration of historical authenticity with contemporary technical performance results in a high-value circular supply chain that honors past achievements while remaining adaptable for future needs. Additionally, this framework promotes socio-technical localism by emphasizing regional expertise and materials in local reconstruction efforts. Such initiatives contribute to fostering a local green economy while simultaneously reducing environmental impacts related to long-distance transportation and emissions. Collectively, these strategies transform heritage buildings into high-performance sustainable hubs. Moreover, this circular methodology combined with smart technologies, including AI optimization and energy management reconceptualizes heritage conservation as a restorative process aligned with the complex socio-technical goals outlined in the SDG 11 framework.

Synergizing Adaptive Reuse and Circular Economy for Socio-Technical Resilience

By merging adaptive reuse with the principles of a circular economy, contemporary urban planners can unlock the potential of existing structures to develop innovative socio-technical solutions while promoting sustainability. Talen (2005) suggests that adaptive reuse plays a vital role in creating vibrant urban spaces by fostering character and identity within the built environment. This approach is socio-technical because such preservation efforts enhance social cohesion and cultivate a strong sense of place, both essential for the long-term psycho-social sustainability of urban areas. Adaptive reuse aligns with the principles of sustainable development by reducing the need for new construction conserving resources and minimising waste (Ahnet al, 2014 in Sanchaniya et al 2025). This practice reduces reliance on vehicular traffic, maintains the intrinsic value of city neighbourhoods, and facilitates the integration of heritage conservation with green urbanism. When applied within the framework of a Circular Economy, adaptive reuse emerges as an advanced method aimed at preserving both structural integrity and cultural significance through what is known as 'metabolic retention'. This strategy transitions from a linear consumption model to a regenerative one, thereby impacting sustainable development across various interconnected socio-technical aspects.

Central to this approach are carbon sequestration and resource preservation; by retaining existing building shells, adaptive reuse mitigates the carbon debt typically associated with new construction projects. Rather than depleting embodied carbon through the extraction of raw materials, this technique operates as a closed-loop material strategy that alleviates ecological

pressures. Additionally, it serves as a means to evaluate environmental impacts while ensuring cultural continuity as social capital by respecting structures that form the backbone of community identity. The preservation of these structures contributes to stabilizing cities amid rapid urbanization and technological advancements, anchoring progress within our historical narrative and collective memory. This human-centered methodology manifests through inclusive participatory development initiatives where adaptive reuse projects become platforms for community-driven endeavors. By involving residents in transformations, new functions, such as smart third places, align closely with genuine social needs, fostering community ownership and resilience over time.

Economic and technical enhancements reinforce this framework when overlooked heritage assets are transformed into intelligent hubs for creativity or commercial activities, propelling the district-level green economy while elevating local property values. Concurrently, environmental performance improves through the incorporation of Smart Infrastructure, which integrates IoT-based energy systems, advanced insulation techniques, and regenerative lighting solutions. These interventions significantly reduce operational footprints in such a way that even traditional buildings can achieve high levels of efficiency and sustainability. Ultimately, adaptive reuse stands out as a crucial avenue for advancing Socio-Technical Building Resilience. The thoughtful alignment of technical engineering standards with human-centric social dynamics ensures our urban environments are not only economically viable but also socially dynamic, culturally rich, and technologically sophisticated. This integrative approach is integral to fulfilling SDG 11's objective to create inclusive, safe, sustainable, and resilient cities prepared for future challenges.

Adaptive Reuse as a Strategic Component of Smart City Planning

Adaptive reuse serves as a strategic approach for implementing smart cities and technologies that can effectively address social, economic, and environmental impacts on a systemic level. In this context, technology acts as an underlying foundation rather than an additional layer on top of existing infrastructures and uses. To fully grasp how adaptive reuse fulfills these objectives, it is essential to examine the theoretical basis of the smart city concept from a socio-technical perspective.

Theoretical Foundations of Smart Urbanism

The conceptualization of smart urbanism transcends mere technological implementation, drawing instead from several interdisciplinary frameworks that effectively bridge the gap between advanced technical infrastructure and complex social systems. Within this integration framework, Information and Communication Technology (ICT) Theory plays a significant role, predicting a future where linking real-world data becomes commonplace. Consequently, the adoption of novel technologies – such as interconnected smart bridges and cloud services – will yield direct repercussions.

In heritage conservation, ICT operates at the intersection of digital innovation by utilizing sensor networks and real-time analytics to enhance building performance, conserve energy, and improve user experience in

historically significant areas. Beyond technology-centric approaches, Socio-Technical Systems (STS) Theory offers insights into viewing cities as interconnected systems. This conceptual framework elucidates how technological interventions or "technical subsystems" interact with established organizational behaviors or human agency, termed "social subsystems", to tackle urban challenges collectively rather than isolating them within distinct subsystems. Moreover, concepts like Urban Metabolism and Circularity characterize cities as biological entities where resources can be efficiently transformed from energy inputs to recyclable materials. Within this metabolic process, adaptive reuse functions as a vital nutrient in urban renewal efforts aimed at aligning smart city growth with sustainable practices for a self-sustaining urban life cycle in a circular economy.

Smart Urbanism highlights the importance of human elements, echoing principles found in New Urbanism and Human-Centricity theories that advocate for walkability and mixed-use developments featuring community gathering places. By integrating technology to foster a lively urban quality of life, thoughtful planning promotes equitable spaces that are accessible to all individuals and communities. Finally, Social Capital and Resilience Theory underscores the significance of social networks in maintaining urban order through its framework. Smart strategies leverage digital technologies to enhance transparency, cooperation, community involvement, social solidarity delivery, and communal resilience, ensuring that such technological progress occurs within supportive environments conducive to higher-quality urban infrastructure.

Human-Centric Smart Planning: The Shirvani Perspective

Based on Hamid Shirvani's concepts, contemporary smart city planning must extend beyond mere technological determinism to highlight the relationship between human-centered design and environmental responsibility. The Shirvani framework provides a strategic approach to integrating heritage buildings into modern urban environments by moving away from solely focusing on technical capabilities to fostering socio-technical harmony within the built infrastructure. Central to this methodology is Human-Centric Design, which emphasizes the importance of enhancing user experience and promoting inclusivity. In heritage conservation, ICT operates at the intersection of digital innovation by utilizing sensor networks and real-time analytics to enhance building performance, conserve energy, and improve user experience in historically significant areas. Beyond technology-centric approaches, Socio-Technical Systems (STS) Theory offers insights into viewing cities as interconnected systems. This conceptual framework elucidates how technological interventions or technical subsystems interact with established organizational behaviours or human agency, termed social subsystems, to tackle urban challenges collectively rather than isolating them within distinct subsystems. Moreover, concepts like Urban Metabolism and Circularity characterize cities as biological entities where resources can be efficiently transformed from energy inputs to recyclable materials. Within this metabolic

process, adaptive reuse functions as a vital "nutrient" in urban renewal efforts aimed at aligning smart city growth with sustainable practices for a self-sustaining urban life cycle in a circular economy.

Furthermore, Shirvani's perspective incorporates regenerative sustainability, which extends beyond resource efficiency to encompass comprehensive environmental stewardship. This includes intentionally integrating green infrastructures and significantly reducing energy consumption while aligning economic development with the preservation of a city's unique natural and cultural assets. Lastly, Shirvani envisions the smart city as a hub for Agile Innovation and Experimentation, where urban areas function as living laboratories facilitating continuous improvement. Not all buildings are constructed with this adaptability in mind; however, repurposing heritage structures offers distinctive opportunities to test advanced technologies like AI-driven climate controls within the constraints of historical architecture. This exploration paves the way for tailored solutions addressing current urban disparities while honoring historical legacies. Consequently, smart heritage transcends merely digitizing history; it aims to establish a resilient social infrastructure. Ensuring that the technical aspects of adaptive reuse align with human-centric planning ultimately promotes restorative relationships within cities that support the broader aims of Sustainable Development Goal 11 (SDG 11).

Aligning Adaptive Reuse with Shirvani's Urban Design Theory: A Socio-Technical Perspective

Hamid Shirvani's urban design paradigm emphasizes the creation of sustainable, livable, and resilient urban ecosystems through human-centricity and community-led engagement. Adaptive reuse serves as a high-performance mechanism to operationalize these goals, bridging the gap between historical infrastructure and contemporary social needs. Within a socio-technical framework, adaptive reuse aligns with Shirvani's principles through the following dimensions:

Table 1 Dimensions of socio technical perspective

Dimensions	Description	Alignment with Shirvani's principles
Regenerative Sustainability	Beyond mere conservation, adaptive reuse minimizes environmental metabolic loads by mitigating waste and reducing the high-impact carbon emissions of new construction	environmental stewardship by treating existing buildings as active, sustainable assets
Enhanced Urban Livability	By transforming heritage shells into vibrant mixed-use developments and restorative "third places,"	human-centric design philosophy, where the built environment is optimized to respond to the physiological and

	adaptive reuse prioritizes user experience	psychological needs of urban residents.
Structural and Social Resilience	Adaptive reuse enhances urban resilience by providing flexible spatial inventories that can adapt to socio-economic shifts	creating resilient urban fabrics that withstand environmental and economic volatility through the intelligent repurposing of existing capital.
Participatory Community Engagement	repurposing of local landmarks often necessitates transparent collaboration between stakeholders, residents, and designers	social ownership and collective accountability, ensuring that the new urban functions are socially relevant and sustainable.

(source: researcher's analysis, 2026)

Socio-Technical Strategies for Architectural and Interior Integration

The practice of adaptive reuse necessitates a careful equilibrium between preserving architectural integrity and implementing advanced interior engineering. Design strategies aimed at fostering a robust regenerative development plan must navigate the delicate balance between technological efficiency and material authenticity. The integration of sustainable materials with intelligent building performance occurs through various critical methods, transforming the interior environment into an effective socio-technical system. Central to this methodology is the transition towards biophilic and regenerative materiality, which serves as a foundational element. To enhance Indoor Environmental Quality (IEQ), designers have the option to substitute traditional synthetic materials with natural, bio-based alternatives such as bamboo or lime-based renders. These natural materials offer superior thermal regulation and reduced VOC emissions compared to their synthetic counterparts, making them essential for promoting safe usage within spaces aimed at restorative effects. This approach not only improves the physical well-being of occupants but also fosters a psychological connection with the natural world, all while honoring heritage.

Furthermore, the framework emphasizes a circular material economy by incorporating salvaged and upcycled elements. This strategy can significantly reduce the environmental footprint of interior renovations while maintaining the "material honesty" inherent in the original structure. For instance, preserving and showcasing historic brickwork or timber serves a dual purpose: it visually enhances authenticity related to cultural heritage while aligning with circular design principles that minimize resource-heavy finishing processes. The technological components of this initiative are defined by intelligent energy management and appliance optimization through high-efficiency systems integrated into historical structures. The operational capacity of buildings is recalibrated to meet contemporary smart city standards by utilizing low-energy devices and IoT sensors for automating lighting and temperature control systems. It is crucial to recognize that these technological enhancements can

deliver high-performance functionality without compromising the built environment through invasive or detrimental alterations to heritage assets.



Figure 4. Elements of sustainable design in spatial design
(source: researcher's analysis, 2025)

In conclusion, the integration of these architectural and interior strategies forms a comprehensive Socio-Technical Sustainable Development Scheme. This approach ensures that heritage structures are not merely physically preserved in a state of stasis, but are technically optimized as high-performance, human-centric nodes. By functioning as vital components of the broader smart city fabric, these repurposed spaces contribute directly to the resilient and inclusive targets of SDG 11.

Interior Engineering as a Socio-Technical Integration Layer for Smart Cities

In the context of smart urbanism, elements of interior design within historic buildings go beyond their conventional aesthetic functions and become the main interface between users and the wider smart city ecosystem. To evolve past traditional repurposing methods, these design components must be developed as responsive parts of a socio-technical system, transforming historical interiors into high-performance elements. This is achieved through dynamic spatial flexibility, where modular spaces are crafted for quick reconfiguration. Such adaptability aligns with the principles of agile urbanism, enabling heritage environments to fluidly shift among commercial, social, and co-working purposes without creating additional structural waste or necessitating intrusive alterations.

Additionally, this approach highlights systemic multifunctionality and density optimization to navigate the limitations posed by historic structures. By employing multifunctional fixtures, designers can enhance spatial efficiency and boost activity density within existing structures, an essential principle of compact smart city planning that advocates for effective land utilization. This physical enhancement is further supported by the integration of intelligent infrastructure, wherein technology is seamlessly incorporated into the building's operational

framework. Through features such as smart lighting, automated HVAC systems, and thermal control mechanisms, historical interiors evolve into energy-efficient, interconnected nodes that significantly contribute to the overarching digital infrastructure of the city.

The social aspect of this engineering layer prioritizes universal accessibility and social equity. By integrating advanced technologies like AI-assisted navigation and haptic feedback systems, heritage spaces are transformed into inclusive environments catering to various physical requirements. This commitment to aligning with the "Smart People" and "Smart Living" pillars of urban development ensures equitable access to cultural resources for all community members. Ultimately, this framework is reinforced through sophisticated safety and security measures that employ real-time occupancy monitoring alongside AI-driven security systems. Such integrations guarantee that publicly accessible heritage sites maintain safety, resilience, and manageability within modern urban settings while effectively balancing historical preservation with contemporary technological needs.

The Triple-Helix Synthesis of Adaptive Reuse, Sustainability, and Smart Planning

The convergence of adaptive reuse, sustainable development, and smart city strategies forms a triple-helix support scheme that drives regenerative urban renewal. Within this framework, adaptive reuse acts as the physical foundation, providing the structural capital necessary to support sustainable development goals. This intersection is characterized by a metabolic approach to construction, where the preservation of architectural and interior features, such as original facades, structural systems, and decorative ornaments, functions as a high-value recycling strategy. By retaining these elements, the scheme effectively reduces the environmental burden of new construction, preserving the embodied carbon of heritage assets while simultaneously safeguarding the cultural identity and sense of place that are vital for the social sustainability of urban communities.

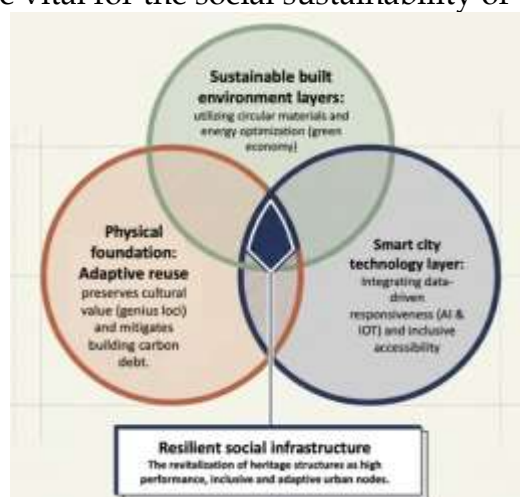


Figure 5. Triple helix synthesis of adaptive reuse, sustainability and smart planning

(source: researcher's analysis, 2026)

Furthermore, the integration of smart city strategies within this sustainable framework transforms static heritage buildings into high-performance, responsive urban nodes. This technological layer is operationalized through the installation of energy-efficient lighting and AI-driven sensor arrays, which synchronize the building's operational performance with the real-time needs of the user. The synergy between sustainability and smart technology is further evidenced by the implementation of biophilic infrastructure, such as green walls, which improve air quality while being managed by intelligent irrigation systems. Ultimately, by incorporating accessibility and safety features enhanced by AI, the support scheme ensures that repurposed spaces are not only environmentally responsible but also socially inclusive. This synthesized approach creates a resilient social infrastructure that elevates the overall quality of urban life, directly fulfilling the integrated mandates of the SDG 11 framework.

Table 2 Strategic dimensions to create social infrastructure resilience

Strategic Dimension	Adaptive Reuse (Physical/Cultural Layer)	Sustainable Development (Environmental Layer)	Smart City Planning (Technological Layer)	Resulting Social Infrastructure Resilience
Materiality & Resources..	Structural Fidelity: Preservation of facades, ornaments, and heritage archetypes	Material Circularity: Use of recycled and upcycled materials to reduce ecological footprint.	Resource Monitoring: Data-driven tracking of material lifecycles and waste.	Ecological Resilience: Minimizes carbon debt while maintaining cultural anchors.
Spatial Functionality ..	Repurposed Archetypes : Converting obsolete sites into coworking or community hubs	Density Optimization: Maximizing spatial utility within existing footprints.	Technological Responsiveness: AI-optimized space usage based on real-time user needs.	Adaptive Resilience: Created "Third Places" that evolve with community demands.
Environmental Performance.	Passive Design: Leveraging original thick walls and natural ventilation.	Biophilic Integration: Green walls and infrastructure for air quality and restoration.	Intelligent Metabolism: IoT sensors for automated energy and HVAC management.	Environmental Resilience: High-performance buildings that mitigate heat island effects.

Human & Social Impact..	Collective Memory: Safeguarding identity and sense of place	Psychological Well-being: Creating healthy, restorative indoor environments (IEQ).	Technical Human-Centricity: AI-enhanced safety, security, and universal accessibility.	Social Resilience: Inclusive and equitable access to heritage and modern services.
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By aligning these elements, designers and urban planners can ensure that heritage structures are not merely preserved in a state of stasis, but are reborn as high-tech, human-centric, and environmentally restorative components of the future city.

CONCLUSIONS AND RECOMMENDATIONS

Smart city planning necessitates the strategic convergence of technological innovation and resource efficiency to enhance urban livability and environmental stewardship. This research demonstrates that adaptive reuse is not merely a conservation alternative but a fundamental driver of contemporary smart urbanism. By repurposing existing materials and recycling building components instead of engaging in carbon-heavy demolition, urban areas can transform outdated structures into active assets. These include dynamic mixed-use centers, cultural hubs, and modern coworking spaces. This approach capitalizes on existing structural resources, creating dense, efficient, and sustainable urban ecosystems.

Table 3 Blueprint of regenerative socio-technical

Material & Resources	Physical (fidelity & real structure)	+	Environmental (upcycle material circularity)	+	Technology (material cycle observation)	=	Ecological resilient (carbon debt minimalization)
Spatial functionality	Physical (old sites conversion to communal hub)	+	Environmental (density optimization)	+	Technology (AI adaptive spatial design optimization)	=	Adaptive resilient (third places evolution)
Environmental performance	Physical (passive thick wall ventilation)	+	Environmental (biophilic/ green wall integration)	+	Technology (automatic IoT metabolism)	=	Environmental resilient (heat island effect mitigation)
Human and Social impact	Physical (restoring collective memory)	+	Environmental (psychological health/ IEQ)	+	Technology (universal accessibility/ AI safety)	=	Social resilient (inclusive heritage access)

Integrating intelligent technologies into historical buildings is one strategy that enhances this transformation. The incorporation of IoT sensors, AI-driven automation systems, and high-efficiency mechanical systems within traditional frameworks helps elevate older buildings to current operational standards. Such technological enhancements, along with regenerative design features like biophilic infrastructure and green roofs, not only mitigate the urban heat island effect and improve air quality but also convert static structures into flexible

components of an interconnected city. Ultimately, this article posits that harmonizing smart technology with heritage preservation establishes an effective Socio-Technical Framework for urban renewal. Adaptive reuse presents a resilient approach to development that reconciles technological advancement with the need to restore buildings for local communities. This framework ensures that historical structures are transformed into sustainable and inclusive environments: safe, technologically advanced, and accessible spaces that align with the broader objectives outlined in Sustainable Development Goal 11 (SDG 11). As cities embrace digital transformation, preserving cultural narratives through intelligent adaptive reuse may offer a vital means of maintaining focus on humanity's role in the 21st century.

ADVANCED RESEARCH

This study highlights adaptive reuse as a key strategy in smart city development, integrating technological innovation with resource efficiency to create sustainable and resilient urban systems. By transforming existing buildings into multifunctional assets and incorporating smart technologies such as IoT and AI, cities can enhance operational performance while reducing environmental impact. Supported by regenerative design approaches, this framework aligns urban renewal with the goals of sustainability, inclusivity, and cultural preservation under SDG 11.

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